Journal of Athletic Training 2024;59(8):845–856
doi: 10.4085/1062-6050-0680.22

Is an Exercise-Based Injury-Prevention Program Effective in Team Handball Players? A Systematic Review and Meta-Analysis

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Objective: To assess the effectiveness of exercise-based injury-prevention programs in preventing sports injuries in team handball players.

Data Sources: Scopus, PubMed, Web of Science, SPORTDiscus, and CINAHL from inception until April 2023.

Study Selection: Studies were included if they were randomized controlled trials or prospective cohort studies, contained a population of competitive team handball players, included an intervention designed specifically to prevent or reduce the risk of team handball injuries, and reported injury incidence rates specific to team handball players. Two researchers independently evaluated studies for inclusion and assessed their methodological quality.

Data Extraction: Study design, intervention details, participant characteristics, and the number of injuries in each group were extracted from each study by 2 independent researchers. The outcome of interest was the incidence rate of injury. Injury data were classified into 5 groups: shoulder injuries, lower extremity injuries, knee injuries, anterior cruciate ligament injuries, and ankle injuries. Extracted data were analyzed using a random-effects model to compute the overall effect estimates of injury-prevention programs in reducing the risk of injuries. Odds ratios (ORs) with 95% CIs were calculated based on the number of injuries in each group.

Data Synthesis: Meta-analyses were conducted independently for each injury classification. Results indicated that prevention programs reduced the risk of shoulder injuries (OR = 0.60; 95% CI = 0.42, 0.85; P = .004), lower extremity injuries (OR = 0.59; 95% CI = 0.37, 0.95; P = .03), knee injuries (OR = 0.53; 95% CI = 0.35, 0.78; P = .002), anterior cruciate ligament injuries (OR = 0.66; 95% CI = 0.45, 0.96; P = .03), and ankle injuries (OR = 0.57; 95% CI = 0.40, 0.81; P = .002) in team handball players.

Conclusions: In team handball players, injury-prevention programs appear to effectively reduce the risk of shoulder, lower extremity, knee, ankle, and anterior cruciate ligament injuries.

Key Words: shoulder injury, lower extremity injury, knee injury, ankle injury, anterior cruciate ligament injury

Key Points

- Exercise-based injury-prevention programs show efficacy in reducing team handball injury risks, yet the scarcity and quality limitations of existing studies suggest the need for higher-quality research to strengthen recommendations.
- Exercise-based injury-prevention programs can reduce the risk of injuries to the shoulder (from 15% to 58%), lower extremity (from 2% to 63%), knee (from 22% to 65%), anterior cruciate ligament (from 3% to 55%), and ankle (from 19% to 60%) in team handball players.
- Given the relatively small number and quality of studies on this topic, higher-quality studies may help to improve the strength of the recommendations.

Team handball is one of the most popular ball sports, played by nearly 20 million people around the world.[1] Handball is played by 2 teams of 7 field players in two 30-minute periods. Teams include 5 substitute players who can be substituted at any time during the game. Players use their hands to pass a ball with the aim of throwing it toward the opposing team's goal, and the team that scores the most goals is the winner. Researchers have shown that playing team handball improves several physical and physiological variables.[2] However, participation in handball is also associated with a high risk of injury mainly because players are exposed to high physical demands during training sessions and games.[1,3] Team handball is a high-intensity contact sport, involving repeated acceleration and deceleration movements, fast sidestep cutting and pivoting maneuvers, sudden jumping and landing movements, and frequent throws.[1,4–6] In addition, professional players endure busy competition schedules (between 70 and 100 international, national, and club competitions) and intense training pressures to stay at a competitive level, which probably contributes to the high prevalence of injuries in team handball.[4,7,8] At the elite level, the increase in the number of national or international matches and tournaments has resulted in a typical season lasting 9 to 10 months.[9] During the season, elite players typically play 2 matches per week compared with 1 match at lower levels of play, and in different periods, elite players often train twice each day.[9]

Compared with other team sports, team handball had the third highest risk of injury in 2008 (after soccer and field hockey), second highest in 2012 (after soccer), and fourth highest in 2016 (after soccer, rugby, and water polo).[8,10,11] The overall incidence of injury in team handball has been reported to be between 10 and 40 injuries per 1000 player hours, with most injuries occurring during matches.[10,11] The most frequent injuries occur in the lower limbs (thigh, knee, and ankle), the shoulder, and the upper limbs.[3,12] Nearly half of all team handball injuries involve the knee and ankle, with ankle injuries being the most frequently reported (8% to 45%); although anterior cruciate ligament (ACL) injuries occur less frequently (7% to 27%), they are more severe.[3,5,11–13] Hand-joint injuries constitute around 9.9% of injuries, and those to the shoulder joints amount to 9.3%.[9] Even though the incidence of shoulder injuries is relatively low, they require the third-longest interval of convalescence after trauma (after knee and ankle injuries).[9] Injuries not only affect players' health and performance but also affect the sports team and athlete's family and, in the long term, may lead to early joint degeneration, especially in the knee.[14–16]

Injury prevention should be a primary goal for handball players of all ages and participation levels (eg, recreational, semiprofessional, and professional) because injuries will result in not only athletic performance deficits, an increased risk of reinjury, and chronic sequelae but also loss of playing time and a high financial burden for professional athletes' employers and the health care system.[17] However, it remains unclear whether injury-prevention programs diminish the incidence of injuries in handball players. Therefore, the aim of our systematic review and meta-analysis was to assess the effectiveness of exercise-based injury-prevention programs in preventing sport injuries in team handball players. We hypothesized that the literature would present inconsistent results on the prevention of injuries in handball players, ultimately resulting in no evidence that exercise-based injury-prevention programs reduce lower extremity, ankle, and ACL injury risk in this population.

METHODS

Study Design

This systematic review and meta-analysis was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement.[18] This protocol was registered in PROSPERO in December 2021 (CRD42021295239).

Search Strategy

The literature search was independently conducted by 2 researchers (A.N. and F.S.). Relevant studies were identified through an internet-based search in 5 health-related, biomedical, and psychological databases (Scopus, PubMed, Web of Science, SPORTDiscus, and CINAHL). No filters or limitations were imposed during any of the database searches. The search was carried out from inception to April 2023. Relevant search keywords were combined with Boolean operators (OR and AND) and applied to 3 search levels (Table 1).

Table 1. Levels and Terms of the Literature Search Process

Search Level	Search Terms With Boolean Operators
1	(handball[Title/Abstract])
2	AND (injury[Title/Abstract] OR Injuries[Title/Abstract] OR tear[Title/Abstract] OR dislocate[Title/Abstract] OR break[Title/Abstract] OR sprain[Title/Abstract] OR twist[Title/Abstract] OR strain[Title/Abstract] OR tearing[Title/Abstract])
3	AND (prevention[Title/Abstract] OR exercise[Title/Abstract] OR training [Title/Abstract] OR conditioning[Title/Abstract] OR preparation[Title/Abstract] OR warm-up[Title/Abstract] OR intervention [Title/Abstract])

The bibliographic references of identified studies were searched manually for additional relevant studies. All eligible studies were entered into Google Scholar (Google) to identify all articles that had cited them.

Retrieved articles from each database were imported into EndNote X7 (Thomson Reuters) software for duplicate removal, screening, and review. After accounting for duplication, we judged the eligibility of returned articles by screened title and abstract. When study selection was unclear after reading the title or the abstract, we screened the full text of the article. Studies were screened using the predetermined inclusion and exclusion criteria by 2 independent reviewers (A.N. and F.S.). When conflicts arose, these authors discussed the manuscript to reach a consensus. If consensus was not achieved, a third reviewer (M.K.) was consulted.

Eligibility Criteria

The inclusion criteria, according to the population, interventions, comparisons, outcomes, and study design model, were as follows: (1) population: competitive handball players of any age (eg, professional, collegiate, and scholastic intramural).[18] (2) Interventions: The intervention program was designed specifically to prevent or reduce the risk of team handball injury (overall or region-specific injury-prevention programs). The exercise-based injury-prevention program had to be multifaceted and include sport-specific skills, resistance, balance, or plyometric exercises. Sport-specific exercises mimic specific technical skills, such as landing and throwing techniques, that apply directly to handball. *Resistance exercises* were defined as activities that improve muscle strength using resistance, such as body weight, free weights, elastic bands, or strength machines. *Balance exercises* were defined as activities that require maintaining the line of gravity at the base of support, such as single- or double-legged stance activities, that were designed to improve proprioceptive awareness. Activities were characterized as *plyometric exercises* if they used powerful movements, such as jumping or bounding. (3) Comparisons: At least 1 control group that did not receive any intervention was included. (4) Outcomes: The incidence rate of the injury or other outcome data such as injury counts and athlete exposures that made it possible to calculate incidence rate was reported. (5) Study design: A randomized controlled trial or prospective cohort study design was used. In addition, included studies were (6) full-text articles published in English in peer-reviewed journals.

All types of multicomponent exercise interventions to prevent team handball injuries were selected, but interventions using protective devices (eg, braces and tapes) or including only 1 exercise component (eg, using Nordic eccentric exercise to prevent hamstrings injuries) were excluded. Case studies, lectures, commentaries, editorials, review articles, and articles that were not peer-reviewed or not written in English were excluded.

Quality Assessment

The risk of bias for the randomized controlled trials and prospective cohort studies was independently assessed by 2 reviewers (A.N. and F.S.) using the Physiotherapy Evidence Database (PEDro) scale.[19,20] The PEDro scale is a valid and reliable measure of the methodological quality of randomized controlled trials in systematic reviews.[19,20] It is an 11-item scale with each item scored as *yes* or *no*. The first item pertains to external validity and is not used to compute the overall quality score. The remaining 10 items (items 2–11) are summed to obtain a final PEDro score out of 10; a higher score reflects higher methodological quality. A PEDro score of $\geq$6 indicates the study is of *high quality*; 4 to 5, *moderate quality*; and $\leq$3, *low quality*.[20]

Whereas it was initially developed to assess the quality of randomized controlled trials in physiotherapy literature, the PEDro scale has been used to evaluate a diverse range of study designs.[19–21] However, using this scale to assess studies that are not randomized controlled trials often results in lower scores due to the absence of randomization, which is a specific criterion on this scale. Given the limitations of the PEDro scale in evaluating observational studies, the Newcastle-Ottawa Scale (NOS) was chosen to further analyze the methodological strengths and weaknesses of the included cohort studies.[22] The NOS is used to assess bias in prospective studies using 3 criteria: participant selection (4 aspects), comparability (1 aspect), and outcomes (3 aspects). Each criterion is scored from 0 to 1 or 0 to 2, totaling a maximum of 9 points. The quality of studies is categorized as *low* (0–3 points), *moderate* (4–6 points), or *high* (7–9 points). The NOS stands as a comprehensive, validated tool used for assessing the quality of studies that are not randomized controlled trials in meta-analysis.[23]

Disagreements regarding PEDro scoring were resolved by discussion between the reviewers. If consensus was not achieved, a third reviewer (M.K.) was consulted. All studies were scored and entered into an individual spreadsheet.

Data Extraction and Analysis

Two authors (A.N. and F.S.) independently extracted data using a specifically designed standardized form and compared the extracted data for consistency. Any discrepancies between the 2 forms were resolved during a consensus meeting. The study design, country, competitive level, study population (sex, size, and age), size of control and intervention groups, dropout rate, details of the intervention (type, duration, and frequency), and number of injuries per group were extracted. Injuries included all injuries (overuse and traumatic) sustained during the study period in training and match play. Data were classified into 5 groups based on the anatomic location of the injury (shoulder injuries, lower extremity injuries, knee injuries, ankle injuries, and ACL injuries). When applicable, data from a single study were included in >1 group. A *lower extremity injury* was defined as any injury (acute or chronic and traumatic or nontraumatic) incurred during competition or training directly related to handball and involved 1 of the lower parts of the body from the hip to the toes. If this injury was limited to the knee, it was defined as a *knee injury*; if it was limited to the ankle, it was defined as an *ankle injury*; and if it involved the ACL, it was defined as an *ACL injury*.

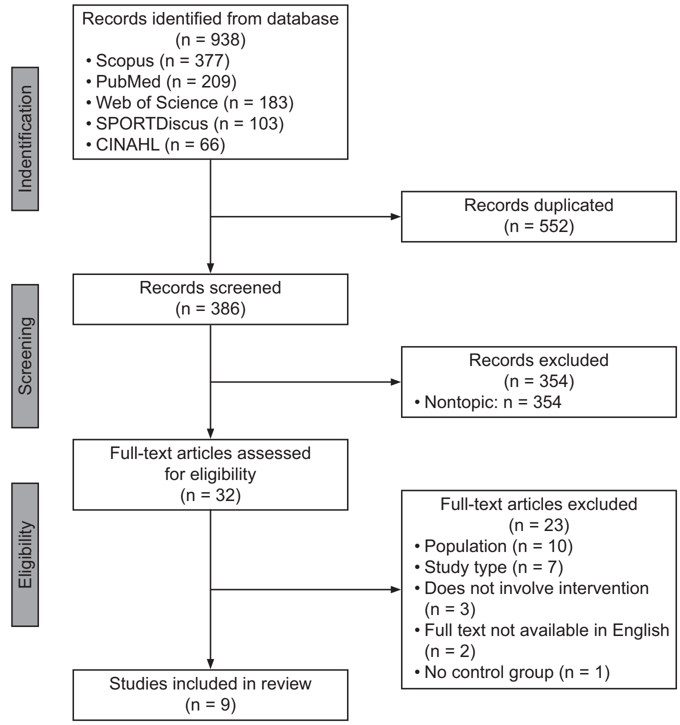

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses flow diagram of the search and study selection process.

Data Synthesis

Meta-analyses were undertaken with Comprehensive Meta-Analysis (version 3.0; Biostat, Inc) using a random-effects model to compute the overall effect estimates of injury-prevention programs in reducing the risk of shoulder, lower extremity, knee, ACL, and ankle injuries. Odds ratios (ORs) with 95% CIs were calculated based on the number of injuries in each group. Statistical heterogeneity was assessed using the I^2 statistic to describe the proportion of the observed variability in effect among studies that is due to true differences in effect. An I^2 value of 0% indicates *no heterogeneity*; 30% to 60%, *moderate heterogeneity*; and >75%, *considerable heterogeneity*.[24,25] Publication bias was assessed via visual inspection of a standard funnel plot, Orwin fail-safe N, and Egger regression test. The α level was set at .05.

RESULTS

Search Results

The initial database search using the Scopus, PubMed, Web of Science, SPORTDiscus, and CINAHL databases yielded 938 results. After removing duplicates, we screened 386 articles for relevancy. Screening by title and abstract yielded 32 potentially eligible articles, and after a full-text review, 23 were excluded. A total of 9 studies were included in the final analysis. A flowchart of the selection process is displayed in Figure 1.

Table 2. Characteristics of the Exercise-Based Prevention Programs Attempting to Reduce Sport Injuries in Handball Players Extended on Next Page

Study (Year)	Study Design	Country; Competition Level	Sex, No. (Age Range, y)	Dropout Rate	Intervention
Achenbach et al[26] (2018)	Prospective cohort	Germany; under 16 and 18	105 Male, 174 female (13–18)	Both groups, ∼31%	The multi-intervention training program included jump and landing, proprioceptive, plyometric, and strength exercises for the quadriceps, hamstrings, and core muscles.
Andersson et al[27] (2017)	Randomized controlled trial	Norway; 2 top divisions	339 Male, 321 female (21.6–23.5)	Intervention, 3.8%; control, 1.2%	The prevention program consisted of 5 exercises aimed at increasing the glenohumeral internal rotation, increasing external-rotation strength, and improving scapula control and kinetic chain and thoracic mobility.
Myklebust et al[34] (2003), season 1	Prospective cohort	Norway; Division I–III	1745 Female (21–22)	Intervention, 2.6%; control, 3.1%	A 5-phase multi-intervention training program: balance exercises and planting or landing skills.
Myklebust et al[34] (2003), season 2	Prospective cohort	Norway; Division I–III	1746 Female (21–22)	Intervention, 2.6%; control, 3.1%	A 5-phase multi-intervention training program: balance exercises and planting or landing skill.
Olsen et al[28] (2005)	Randomized controlled trial	Norway; 16- to 17-y divisions	251 Male, 1586 female (15–17)	Intervention, 3%; control, 2.1%	The multi-intervention training program included running exercises, cutting- and landing-technique training, balance training, and strength and power training.
Østerås et al[29] (2014)	Prospective cohort	Norway; 15- to 16-y divisions	15 Male, 94 female (15–20)	Intervention, 28%; control, 27%	The prevention program consisted of push-ups plus standing glenohumeral internal and external rotation with elastic-band resistance.
Petersen et al[31] (2005)	Prospective cohort	Germany; semiprofessional and amateur	276 Female (>19)	Intervention, 9.7%; control, 12.6%	Information about injury mechanisms, balance-board exercises, and jumping and landing training.
Sommervold and Østerås[30] (2017)	Randomized controlled trial	Norway; 16-y divisions	87 Female (>17)	Intervention, 13.2%; control, 22.6%	The prevention program consisted of 2 exercises to strengthen the shoulder complex.
Wedderkopp et al[32] (2003)	Prospective cohort	Norway; recreational to elite	163 Female (14–16)	Not reported	Wobble-board exercise and 1 functional exercise for all major muscle groups including both upper and lower extremities.
Wedderkopp et al[33] (1999)	Prospective cohort	Norway; recreational to elite	237 Female (16–18)	Not reported	Wobble-board exercise and 1 functional exercise for all major muscle groups including both upper and lower extremities.

Abbreviation: PEDro, Physiotherapy Evidence Database.
[a] *As usual* indicates athletes were engaging in regular team activities or routines.

These articles were categorized into shoulder injury (n = 5), lower extremity injury (n = 5), knee injury (n = 5), ankle injury (n = 5), and ACL injury (n = 4).[26–34] All analyzed articles are summarized in Table 2.

Study Characteristics

The 9 included studies comprised 7139 participants with a median sample size of 275 (range, 87–1837) per study. We allocated 3543 players to an intervention group and 3596 players to a control group that was engaged in regular team activities or routines (Table 2). The study by Myklebust et al was conducted across 2 separate seasons and, therefore, is considered 2 distinct studies.[34] Three studies were randomized controlled trials, and 6 studies were prospective cohort studies.[26–34] Two studies were conducted in Germany, and 7 were conducted in Norway.[26–34] All studies were published between 1999 and 2018.[26,33] The mean age of players in the reviewed studies ranged from 14.9 to 23.5 years.[27,32] Except for the study by Petersen et al that included only adult players, all reviewed studies included handball players aged <22 years.[31] Five studies only included female athletes, and 4 studies comprised cohorts with both male and female athletes.[26–34] All included studies had a follow-up period of 1 season with a median intervention duration of 8 months (range, 6–9 months) and median of 66 training sessions (range, 45–126 sessions).[28,32,33] The dropout rate ranged from 1.2% to 31% but was not reported in 2 studies.[27–30]

Quality Assessment

Interrater agreement for quality analysis between the 2 reviewers (A.N. and M.K.) assessing the 9 included studies was 95.4%. The PEDro scores ranged from 3 to 9 points,

Table 2. Extended From Previous Page

Control[a]	Duration	Frequency, No. of Times/Week	Total No. of Player Seasons	Total No. of Training Sessions	Total Training Time, h	PEDro Score
As usual	Pre- and in-season for 9 mo	Preseason, 2–3; in-season, 1	Intervention, 168; control, 111	56	13.9	4
As usual	In-season for 6 mo	In-season, 3	Intervention, 331; control, 329	75	12.5	9
As usual	Pre- and in-season for 6–7 mo	Preseason, 3; in-season, 1	Intervention, 832; control, 913	55	13.8	4
As usual	Pre- and in-season for 6–7 mo	Preseason, 3; in-season, 1	Intervention, 833; control, 913	55	13.8	4
As usual	In-season for 8 mo	Every training and competition	Intervention, 958; control, 879	45	13.5	9
As usual	In-season for 8 mo	In-season, 3	Intervention, 53; control, 56	96	16	3
As usual	Pre- and in-season for 8 mo	Preseason, 3; in-season, 1	Intervention, 134; control, 142	55	9.8	3
As usual	In-season for 7 mo	In-season, 3	Intervention, 46; control, 41	79	13.2	4
As usual	In-season for 9 mo	In-season, 2–5	Intervention, 77; control, 86	126	21	4
As usual	In-season for 9 mo	In-season, 2–5	Intervention, 111; control, 126	126	21	4

with a mean score of 5 points (Table 3). Two studies were considered to be of high methodological quality, 5 studies were rated as having moderate quality, and 2 were of low quality.[26–34] Some limitations in the low- and moderate-quality studies were the lack of reporting participant eligibility criteria, randomization, and adequate allocation concealment.[26,28–34] Some studies did not blind participants, therapists, or assessors or describe the blinding status for participants and therapists.[26,29–34] In addition, the high dropout rate and absence of conducting an intention-to-treat analysis were the most common limitations in the reviewed studies.[26,27,29–34]

The NOS scores for the cohort studies ranged from 6 to 8 points, with a mean score of 7 points, indicating moderate to high methodological quality. Some limitations observed in the studies included deficiencies in the ascertainment of exposure, the adequacy of follow-up of cohorts, and the assessment of outcomes.[26,27,29,31–34]

Shoulder Injuries

Five studies reported the effects of an exercise-based injury-prevention program on shoulder injuries.[26–30] Among those studies, 3 reported that exercise-based injury-prevention programs are associated with a lower risk of shoulder injuries, and 2 did not conduct statistical analysis.[26–30] The meta-analysis showed that using an exercise-based injury-prevention program is associated with a lower risk of shoulder injury in handball players (OR = 0.60; 95% CI = 0.42, 0.85; P = .004; Figure 2). Heterogeneity was zero and not different (P = .48) in these analyses.

Lower Extremity Injuries

Five studies reported the effects of an exercise-based injury-prevention program on lower extremity injuries.[26,28,31–33] Among those studies, 2 reported that exercise-based injury-

Table 3. **Methodological Quality Assessment for Eligible Studies**[a]

Study (Year)	Random Allocation	Concealed Allocation	Baseline Similarity	Subject Blinded	Therapist Blinded	Assessor Blinded	Dropout Rate	Intention-to-Treat Analysis	Between-Groups Comparison	Points Measured	Overall Study Quality
Achenbach et al[26] (2018)	No	No	Yes	No	No	No	Yes	No	Yes	Yes	4/10
Andersson et al[27] (2017)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	9/10
Myklebust et al[34] (2003), season 1	No	No	Yes	No	No	No	Yes	No	Yes	Yes	4/10
Myklebust et al[34] (2003), season 2	No	No	Yes	No	No	No	Yes	No	Yes	Yes	4/10
Olsen et al[28] (2005)	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9/10
Østerås et al[29] (2014)	No	No	Yes	No	No	No	Yes	No	No	Yes	3/10
Petersen et al[31] (2005)	No	No	No	No	No	No	Yes	No	Yes	Yes	3/10
Sommervold and Østerås[30] (2017)	Yes	No	Yes	No	No	No	Yes	No	No	Yes	4/10
Wedderkopp et al[32] (2003)	No	No	Yes	No	No	Yes	No	No	Yes	Yes	4/10
Wedderkopp et al[33] (1999)	No	No	Yes	No	No	Yes	No	No	Yes	Yes	4/10

[a] Physiotherapy Evidence Database scoring components. Scores of $\geq$6 are considered high methodological quality.

prevention programs are associated with a lower risk of lower extremity injuries, 2 did not report an association between exercise-based injury-prevention programs and a risk of lower extremity injury, and 1 did not conduct statistical analysis.[26,28,31–33] The meta-analysis showed that using an exercise-based injury-prevention program is associated with a lower risk of lower extremity injury in handball players (OR = 0.59; 95% CI = 0.37, 0.95; P = .03; Figure 3). Heterogeneity was high (I^2 = 65.6%) and different (P = .03). A classic fail-safe N test indicated that 17 additional studies would need to be included to nullify the statistical significance of the meta-analysis.

Knee Injuries

Five studies reported the effects of an exercise-based injury-prevention program on knee injuries.[26,28,31–33] Among those studies, 2 reported that exercise-based injury-prevention programs are associated with a lower risk of knee injuries, and 3 did not report an association between exercise-based injury-prevention programs and a risk of knee injury.[26,28,31–33] The meta-analysis showed that an exercise-based injury-prevention program is associated with a lower risk of knee injury in handball players (OR = 0.53; 95% CI = 0.35, 0.78; P = .002; Figure 4). Heterogeneity was zero and not different in these analyses (P = .89).

ACL Injuries

Five studies reported the effects of an exercise-based injury-prevention program on ACL injuries.[26,28,31,34] Among those studies, 2 reported that exercise-based injury-prevention programs are associated with a lower risk of ACL injuries, and 2 did not report an association between exercise-based injury-prevention programs and a risk of ACL injury.[26,28,31,34] The meta-analysis showed that an exercise-based injury-prevention program is associated with a lower risk of ACL injury in handball players (OR = 0.66; 95% CI = 0.45, 0.96; P = .03; Figure 5). Heterogeneity was zero and not different in these analyses (P = .44).

Ankle Injuries

Five studies reported the effects of an exercise-based injury-prevention program on ankle injuries.[26,28,31–33] Among those studies, 2 reported that exercise-based injury-prevention programs are associated with a lower risk of ankle injuries, and 3 did not report an association between exercise-based injury-prevention programs and a risk of ankle injury.[26,28,31–33] The meta-analysis showed that an exercise-based injury-prevention program is associated with a lower risk of ankle injury in handball players (OR = 0.57; 95% CI = 0.40, 0.81; P = .002; Figure 6). Heterogeneity was zero and not different in these analyses (P = .42).

DISCUSSION

Handball is a team throwing sport characterized by frequent and rapid overhead throwing at high velocity and high tempo, with rapid changes of movement, jumps with hard landings, and frequent contact and collisions between opponents distinguishing it from other multidirectional sports. Therefore, this sport has a high injury rate. However, at the time of our study, no meta-analysis that specifically evaluated the effects of

Study and Subgroup	Odds Ratio (95% CI)	*Z* Value	*P* Value
Achenbach et al,[26] (2018)	1.329 (0.239, 7.383)	0.325	.75
Olsen et al,[28] (2005)	0.331 (0.105, 1.043)	−1.888	.06
Andersson et al,[27] (2017)	0.678 (0.446, 1.030)	−1.823	.07
Østerås et al,[29] (2014)	0.299 (0.090, 0.996)	−1.966	.049
Sommervold and Østerås,[30] (2017)	0.574 (0.205, 1.606)	−1.057	.29
Total	0.60 (0.42, 0.85)		

Heterogeneity: $\tau^2 = 0.00$, $\chi^2_4 = 3.5$, $P = .48$, $I^2 = 0.0\%$
Test for overall effect: $Z = -2.92$, $P = .004$

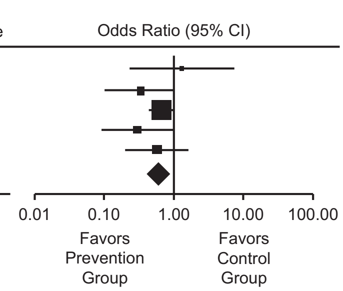

Figure 2. Forest plot of the effect of exercise-based injury-prevention programs on shoulder injuries in handball players.

exercise-based injury-prevention programs in team handball was available. Our meta-analysis indicated that exercise-based injury-prevention programs effectively reduce the risk of shoulder, lower extremity, knee, ACL, and ankle injuries in handball players.

In our systematic review, 3 studies examined the effectiveness of shoulder-specific injury-prevention programs for reducing the risk of shoulder injuries, and 2 studies reported the shoulder injury risk after total-body injury-prevention programs in team handball players.[26–30] We found that team handball–specific injury-prevention programs may reduce the risk of shoulder injuries from 15% to 58%. Interestingly, even whole-body injury-prevention programs reduced shoulder injury risk, which is in line with kinetic chain theory that predicts that impairments or alterations in lower extremity movement patterns or core stability can contribute to abnormal force dissipation and shoulder injuries in team handball athletes.[35–37] Further support for this comes from a systematic review that included 15 full-text articles, in which improved lumbopelvic control was related to improved athletic performance and decreased shoulder injury, and alterations in lower extremity postural stability and core stability were also proposed to affect upper extremity function and contribute to upper extremity injury.[38–40] Therefore, in our study, the 2 studies on whole-body injury prevention using exercises that restore and enhance lower extremity postural stability and core stability can contribute to the observed shoulder-injury prevention. This lower risk of shoulder injury may be related to improved proprioception, coordination, and overall balance, making it possible for players to prevent collisions and unprovoked falls that ultimately can reduce the number of traumatic injuries of not only the lower extremities but also the upper extremities.[32] A closer look at the shoulder-specific injury-prevention interventions in the reviewed studies highlights that the programs should be handball-specific: (1) increasing the glenohumeral internal-rotation range of motion, (2) increasing both glenohumeral external-rotator and scapular-muscle strength, and (3) improving thoracic mobility and the kinetic chain.[27,29,30]

Our meta-analysis indicated that exercise-based injury-prevention programs effectively reduce the risk of injury to the lower extremity from 2% to 63%, the knee from 22% to 65%, the ACL from 3% to 55%, and the ankle from 19% to 60% in handball players. Six studies evaluated the effectiveness of exercise-based injury-prevention programs on injury risk of the lower extremity, knee, ACL, and ankle in team handball players.[26,28,31–34] Although the prevention programs between studies in this review differed in their exercise intensity and duration, almost all focused on the education of proper technique (eg, planting and cutting maneuvers and landing movements), balance training (eg, balancing on 1 limb with eyes closed, balancing on an ankle disk, and balancing on 1 limb while completing a task such as catching or throwing a ball), jumping and landing (plyometric) exercises, and strength training.[26,28,31–33] Given that these programs were multifaceted and addressed many aspects of injury risk (agility, power, strength, balance, joint-position sense, muscle-recruitment patterns, lower extremity alignment, and playing technique), determining precisely which components of these programs were particularly effective in reducing injury risk is difficult. However, all injury-prevention programs were designed based on handball-specific skills, areas of the body that are most susceptible to injury, and risk factors and mechanisms of these injuries. Nevertheless, further studies may be done to shed light on the effects of each component of the injury-prevention programs on injury risk.

Considering that almost all the reviewed studies focused on the proper technique of planting and cutting and jump-landing maneuvers, the reported reduction of ACL injury risk is not unexpected. Approximately 80% of ACL injuries are noncontact injuries and occur in a cutting maneuver or

Study and Subgroup	Odds Ratio (95% CI)	*Z* Value	*P* Value
Achenbach et al,[26] (2018)	0.809 (0.436, 1.502)	−0.671	.50
Olsen et al,[28] (2005)	0.492 (0.358, 0.675)	−4.381	<.001
Petersen et al,[31] (2005)	1.073 (0.576, 1.999)	0.221	.83
Wedderkopp et al,[32] (2003)	0.731 (0.198, 2.692)	−0.472	.64
Wedderkopp et al,[33] (1999)	0.238 (0.112, 0.506)	−3.728	<.001
Total	0.59 (0.37, 0.95)		

Heterogeneity: $\tau^2 = 0.18$, $\chi^2_4 = 11.3$, $P = .03$, $I^2 = 65.6\%$
Test for overall effect: $Z = -2.19$, $P = .03$

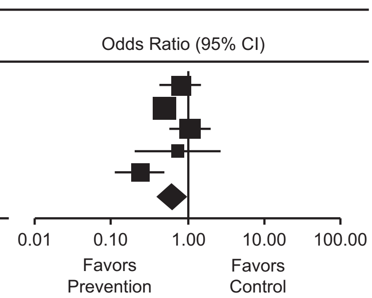

Figure 3. Forest plot of the effect of exercise-based injury-prevention programs on lower extremity injuries in handball players.

Study and Subgroup	Odds Ratio (95% CI)	*Z* Value	*P* Value
Achenbach et al,[26] (2018)	0.743 (0.262, 2.110)	−0.558	.58
Olsen et al,[28] (2005)	0.509 (0.309, 0.838)	−2.653	.008
Petersen et al,[31] (2005)	0.573 (0.187, 1.755)	−0.975	.33
Wedderkopp et al,[32] (2003)	0.553 (0.049, 6.217)	−0.480	.63
Wedderkopp et al,[33] (1999)	0.271 (0.056, 1.302)	−1.630	.10
Total	0.53 (0.35, 0.78)		

Heterogeneity: $\tau^2 = 0.00$, $\chi^2_4 = 1.2$, $P = .89$, $I^2 = 0.00\%$
Test for overall effect: $Z = -3.17$, $P = .002$

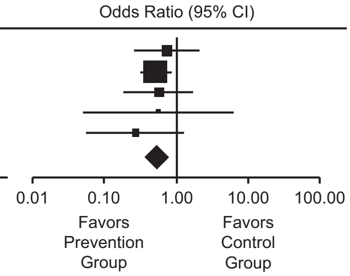

Figure 4. Forest plot of the effect of exercise-based injury-prevention programs on knee injuries in handball players.

1-legged landing after a jump shot.[41] Indeed, education on the proper technique used in the included studies aimed at a narrower stance as well as a knee-over-toe position during planting and cutting maneuvers and landing after a jump movement has been successfully applied to decrease knee varus-valgus moments.[42] Regarding ankle injuries, it also appears that understanding how the foot position at landing in the transverse plane can contribute to reducing the ankle-inversion moment is important to preventing lateral ankle sprains.[43] Other researchers have confirmed that 1 of the main components of any injury-prevention program for the knee and lower extremities is educating athletes on proper technique.[44,45] Given that planting and cutting and jump-landing maneuvers are common movements in team handball, the use of technical education in the injury-prevention programs of this sport can be of great importance.

The other 3 components that were used in most of the reviewed studies were balance, plyometric, and strength exercises. In a systematic review and meta-analysis, Brunner et al concluded that strength and balance exercises were included in all effective injury-prevention programs for lower extremity, knee, ACL, and ankle injuries.[44] Balance exercises in the reviewed studies consisted of single- or double-legged stance activities that were designed to improve proprioceptive awareness. Balance exercises have been used to good effect to prevent lower extremity, knee, ACL, and ankle injuries.[46,47] The risk of injury, such as ankle sprains, has been attributed to poor control of balance and ankle-joint position sense, and balance exercises have been shown to reduce the incidence rate of ankle sprains in the athletic population, irrespective of a history of ankle sprains.[47–49] In another study, using balance board exercises was associated with a reduction in ACL injuries in male soccer players.[50] Balance exercises can enhance the sensorimotor system's ability to adapt to a changing environment and subsequently protect the body from injury. They can also promote the neuromuscular mechanisms responsible for agonist and antagonist cocontraction, which enhance active joint stability.[51] This increased joint stiffness results in less joint laxity and thus less strain on joint structures. Altered kinematics and kinetics of lower extremity joints after the use of balance exercises may be another reason for the reduced risk of sport injuries after these exercises.[52]

Authors of previous studies in which plyometric and specific jumping and landing exercises were incorporated into exercise-based injury-prevention programs demonstrated a reduction in ground reaction force on landing and knee valgus and improved balance between knee-flexor and extensor muscles.[53–55] Given that high ground reaction force, knee valgus, and quadriceps dominance have been identified as risk factors for noncontact ACL injury in athletes, implementing a set of plyometric and specific jumping and landing exercises into exercise-based injury-prevention programs in the included studies may have contributed to the diminished rates of ACL injury.[56,57] Plyometrics can also help improve athletes' lower extremity power, biomechanical technique, joint stability, and neuromuscular control and have the potential to reduce the risk of ankle injuries.[58,59] Researchers have shown that plyometric exercises contribute to a risk reduction of lower extremity injuries that are associated with knee-valgus angles and moments.[60] By facilitating neural adaptations, plyometric exercises can enhance lower extremity muscle activation and proprioception, increasing functional stability and reducing the injury incidence of lower extremity joints.[61,62] Finally, evidence shows that plyometrics induce not only optimal neuromuscular but also bone and musculotendinous adaptation, which can potentially reduce the risk of lower limb sports injuries.[63,64] Therefore, another advantage is that the muscles, joints, and other structures are prepared to tolerate the quick impacts and rebounds needed in the sport. However, in this regard, movement control (knee-over-toe positioning) during plyometric exercises is very important to avoid endangering movement patterns. Therefore, authors of most of the included studies

Study and Subgroup	Odds Ratio (95% CI)	*Z* Value	*P* Value
Achenbach et al,[26] (2018)	0.326 (0.029, 3.643)	−0.910	.36
Olsen et al,[28] (2005)	0.304 (0.082, 1.125)	−1.783	.08
Petersen et al,[31] (2005)	0.206 (0.024, 1.787)	−1.433	.15
Myklebust et al,[34] (2003), season 1	0.867 (0.497, 1.510)	−0.505	.61
Myklebust et al,[34] (2003), season 2	0.635 (0.346, 1.164)	−1.468	.14
Total	0.66 (0.45, 0.96)		

Heterogeneity: $\tau^2 = 0.00$, $\chi^2_4 = 3.7$, $P = .44$, $I^2 = 0.00\%$
Test for overall effect: $Z = -2.18$, $P = .03$

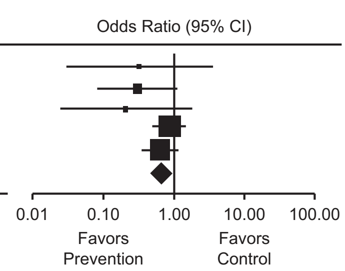

Figure 5. Forest plot of the effect of exercise-based injury-prevention programs on anterior cruciate ligament injuries in handball players.

Study and Subgroup	Odds Ratio (95% CI)	Z Value	P Value
Achenbach et al,[26] (2018)	0.902 (0.351, 2.319)	−0.214	.83
Olsen et al,[28] (2005)	0.592 (0.373, 0.941)	−2.219	.03
Petersen et al,[31] (2005)	0.688 (0.272, 1.739)	−0.791	.43
Wedderkopp et al,[32] (2003)	0.553 (0.049, 6.217)	−0.480	.63
Wedderkopp et al,[33] (1999)	0.256 (0.100, 0.654)	−2.846	.004
Total	0.57 (0.40, 0.81)		

Heterogeneity: $\tau^2 = 0.00$, $\chi^2_4 = 3.9$, $P = .42$, $I^2 = 0.00\%$
Test for overall effect: $Z = -3.17$, $P = .002$

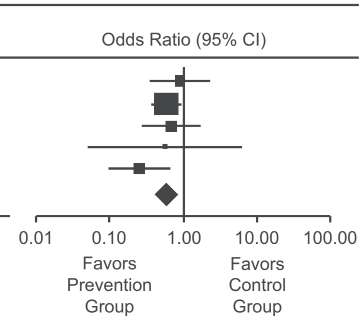

Figure 6. Forest plot of the effect of exercise-based injury-prevention programs on ankle injuries in handball players.

used plyometric exercises with oral feedback to alter the knee-abduction landing pattern.

Another component of the exercise-based injury-prevention programs in our review was strength exercises most commonly used for the hamstrings and core muscles. In their systematic review and meta-analysis, Lauersen et al reported that using strength exercises with balance training enhanced the benefits of an injury-prevention program, and Huxel Bliven and Anderson reported that including only core-muscle exercises in injury-prevention programs resulted in a reduction in knee and ACL injuries.[65,66] The suggested role of strength exercises was to allow the joint to better withstand injurious loads and control lower extremity alignment during specific sport activities. Considering the high loads associated with ankle injuries, it seems that strengthening the ankle stabilizers does not help to prevent injury of this area and the lower extremity.[67] Hence, most of the reviewed injury-prevention programs emphasized strengthening proximal joints (eg, hip and knee joints) instead of the ankle joint, which may be effective in preventing lower limb injuries. Given that the hamstrings muscles, an antagonist of the quadriceps muscles, act as an agonist to the ACL during stop-and-jump tasks, stronger hamstrings muscles may counterbalance the anterior shear force produced by the quadriceps and thereby prevent ACL injuries.[68] The Russian/Nordic hamstrings curl is the most commonly incorporated strength exercise in injury-prevention programs that effectively reduces hamstrings strain and ACL injury.[69] However, a common defect in most prevention programs was the failure to adhere to the principle of progressive overload, which is a fundamental guideline for strength training.[26,28] This oversight can diminish the effectiveness of these strength exercises in reducing the injury risk.[70]

This systematic review and meta-analysis was limited by the relatively small number of studies and low quality of most of the included studies. Among the 9 reviewed clinical trials, 3 had a randomized controlled trial design, and 6 used a prospective cohort study design.[26–34] Randomization is an effective method to reduce potential bias; therefore, a lack of randomization may cause a component of bias that could potentially lead to an overestimation of the intervention effect. However, given that all studies included a control group engaging in regular team activities or routines, the bias introduced by nonrandomization is probably minimal. Another common weakness in the included studies was attrition bias due to high dropout rates and a lack of intention-to-treat analysis.[26,27,29–34] In addition, the heterogeneity analysis for lower extremity injuries demonstrated differences among studies. This can be explained by a limited number of reviewed studies, with a small number of studies making an accurate estimation of heterogeneity difficult.[71]

Another limitation was the possibility of publication bias, as studies published in languages other than English were excluded. However, excluding non-English–language articles usually does not affect the results of systematic reviews.[72]

Compliance should also be considered when evaluating the effectiveness of an exercise-based prevention program, as this can affect the effectiveness of the intervention. Myklebust et al showed that, despite the close follow-up of the teams by physical therapists, acceptable compliance was achieved in less than half of the players.[34] Low compliance was reported in other prevention intervention studies.[30,32]

Although authors of all included studies assessed injury occurrence as a clinical outcome, the results of our review should be interpreted in light of the variety of methods used to collect injury data. Although the definition of *sports injury* and the classification of injury severity were almost the same in all studies, data-collection methods varied, with authors of some studies using self-report, physiotherapist report, and coach report, which may have affected injury recording.[26–28,31,32,41,73] For example, Crossman et al showed that, compared with medical professionals, athletes underestimated the disruption and short-term effects of injury, whereas coaches overestimated them.[74] Because the bias caused by data collection may lead to a biased interpretation of the preventive effect of interventions, future studies should be done to collect accurate data with the help of medical professionals and diagnostic methods to enable the assessment of potential bias in estimating preventive effects.

According to PEDro scores, the overall quality of the included studies was moderate; therefore, higher-quality studies may help to improve the strength of the recommendations. In addition, only 9 handball studies were included in this review, which is consistent with studies that have highlighted the lack of qualitative evidence on basketball injury prevention.[75,76]

One problem, which is inherent in this kind of study, is that we included outcomes of knee, ACL, and ankle injuries, as well as injuries to other areas of the lower extremity (eg, hip, groin, hamstrings, and leg), classifying these as *lower extremity injuries*. However, authors of numerous other review studies have used this reporting pattern, and we expect that the lumping of injuries had a minor effect on the study outcome.[75,76]

For our systematic review, we selected only multicomponent exercise interventions and excluded interventions including 1 exercise component, as we observed in a pilot study that no studies have been done to assess the effectiveness of a specific exercise in preventing injuries in handball players. Future studies can be done to evaluate the effects of such interventions in preventing sport injuries in handball players. Considering that, in our meta-analysis, the CIs for the outcomes of lower extremity and ACL injuries were wide, our results should be interpreted with caution. The width of a CI in a meta-analysis depends on the precision of individual study estimates and the number of studies included.[77] As the number of studies included in a meta-analysis increases, the width of the CI usually decreases. Another limitation was the lack of validation for the PEDro scale in observational studies.[19,20] Despite efforts to assess methodological quality using the NOS, the identified limitations may compromise the strength of the conclusions.

CONCLUSIONS

The primary finding of this systematic review and meta-analysis was that current exercise-based injury-prevention programs may be effective in preventing shoulder, lower extremity, knee, ACL, and ankle injuries in team handball players. However, given the relatively small number and quality of studies on this topic, higher-quality studies may help to improve the strength of the recommendations.

REFERENCES

1. Moller M, Attermann J, Myklebust G, Wedderkopp N. Injury risk in Danish youth and senior elite handball using a new SMS text messages approach. *Br J Sports Med.* 2012;46(7):531–537. doi:10.1136/bjsports-2012-091022
2. Haugen TA, Tønnessen E, Seiler S. Physical and physiological characteristics of male handball players: influence of playing position and competitive level. *J Sports Med Phys Fitness.* 2016;56(1–2):19–26.
3. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury pattern in youth team handball: a comparison of two prospective registration methods. *Scand J Med Sci Sports.* 2006;16(6):426–432. Published correction appears in *Scand J Med Sci Sports.* 2007;17(1):95. doi:10.1111/j.1600-0838.2005.00484.x
4. Newman P, Witchalls J, Waddington G, Adams R. Risk factors associated with medial tibial stress syndrome in runners: a systematic review and meta-analysis. *Open Access J Sports Med.* 2013;4:229–241. doi:10.2147/OAJSM.S39331
5. Langevoort G, Myklebust G, Dvorak J, Junge A. Handball injuries during major international tournaments. *Scand J Med Sci Sports.* 2007;17(4):400–407. doi:10.1111/j.1600-0838.2006.00587.x
6. Rafnsson ET, Valdimarsson Ö, Sveinsson T, Árnason Á. Injury pattern in Icelandic elite male handball players. *Clin J Sport Med.* 2019;29(3):232–237. doi:10.1097/JSM.0000000000000499
7. Soligard T, Schwellnus M, Alonso JM, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. *Br J Sports Med.* 2016;50(17):1030–1041. doi:10.1136/bjsports-2016-096581
8. Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med.* 2013;47(7):407–414. doi:10.1136/bjsports-2013-092380
9. Michalsik LM. On-court physical demands and physiological aspects in elite team handball. In: Laver L, Landreau P, Seil R, Popovic N, eds. *Handball Sports Medicine: Basic Science, Injury Management and Return to Sport*. Springer; 2018:15–33.
10. Junge A, Engebretsen L, Mountjoy ML, et al. Sports injuries during the summer Olympic Games 2008. *Am J Sports Med.* 2009;37(11):2165–2172. doi:10.1177/0363546509339357
11. Soligard T, Steffen K, Palmer D, et al. Sports injury and illness incidence in the Rio de Janeiro 2016 Olympic Summer Games: a prospective study of 11274 athletes from 207 countries. *Br J Sports Med.* 2017;51(17):1265–1271. doi:10.1136/bjsports-2017-097956
12. Vila H, Barreiro A, Ayán C, Antúnez A, Ferragut C. The most common handball injuries: a systematic review. *Int J Environ Res Public Health.* 2022;19(17):10688. doi:10.3390/ijerph191710688
13. Nielsen AB, Yde J. An epidemiologic and traumatologic study of injuries in handball. *Int J Sports Med.* 1988;9(5):341–344. doi:10.1055/s-2007-1025037
14. Giroto N, Hespanhol Junior LC, Gomes M, Lopes A. Incidence and risk factors of injuries in Brazilian elite handball players: a prospective cohort study. *Scand J Med Sci Sports.* 2017;27(2):195–202. doi:10.1111/sms.12636
15. Ekstrand J. Keeping your top players on the pitch: the key to football medicine at a professional level. *Br J Sports Med.* 2013;47(12):723–724. doi:10.1136/bjsports-2013-092771
16. Kujala U, Orava S, Parkkari J, Kaprio J, Sarna S. Sports career-related musculoskeletal injuries: long-term health effects on former athletes. *Sports Med.* 2003;33(12):869–875. doi:10.2165/00007256-200333120-00001
17. Esteve E, Rathleff MS, Bagur-Calafat C, Urrútia G, Thorborg K. Prevention of groin injuries in sports: a systematic review with meta-analysis of randomised controlled trials. *Br J Sports Med.* 2015;49(12):785–791. doi:10.1136/bjsports-2014-094162
18. Liberati A, Altman DG, Tetzlaff J, et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *J Clin Epidemiol.* 2009;62(10):e1–e34. doi:10.1016/j.jclinepi.2009.06.006
19. de Morton NA. The PEDro scale is a valid measure of the methodological quality of clinical trials: a demographic study. *Aust J Physiother.* 2009;55(2):129–133. doi:10.1016/s0004-9514(09)70043-1
20. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther.* 2003;83(8):713–721.
21. Blobaum P. Physiotherapy Evidence Database (PEDro). *J Med Libr Assoc.* 2006;94(4):477–478.
22. Wells GA, Shea B, O'Connell D, et al. The Newcastle-Ottawa Scale (NOS) for assessing the quality of nonrandomised studies in meta-analyses. *Ottawa Hospital Research Institute.* 2011;2(1):1–12. https://www.ohri.ca/programs/clinical_epidemiology/oxford.asp
23. Stang A. Critical evaluation of the Newcastle-Ottawa Scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol.* 2010;25(9):603–605. doi:10.1007/s10654-010-9491-z
24. Higgins JP, Thompson SG. Quantifying heterogeneity in a meta-analysis. *Stat Med.* 2002;21(11):1539–1558. doi:10.1002/sim.1186
25. Deeks JJ, Higgins JPT, Altman DG. Analysing data and undertaking meta-analyses. In: Higgins JPT, Green S, eds. *Cochrane Handbook for Systematic Reviews of Interventions: Cochrane Book Series*. Wiley-Blackwell; 2008:243–296. doi:10.1002/9780470712184.ch9
26. Achenbach L, Krutsch V, Weber J, et al. Neuromuscular exercises prevent severe knee injury in adolescent team handball players. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(7):1901–1908. doi:10.1007/s00167-017-4758-5
27. Andersson SH, Bahr R, Clarsen B, Myklebust G. Preventing overuse shoulder injuries among throwing athletes: a cluster-randomised controlled trial in 660 elite handball players. *Br J Sports Med.* 2017;51(14):1073–1080. doi:10.1136/bjsports-2016-096226
28. Olsen OE, Myklebust G, Engebretsen L, Holme I, Bahr R. Exercises to prevent lower limb injuries in youth sports: cluster randomised controlled trial. *Br J Sports Med.* 2005;330(7489):449. doi:10.1136/bmj.38330.632801.8F
29. Østerås H, Sommervold M, Skjølberg A. Effects of a strength-training program for shoulder complaint prevention in female team handball athletes: a pilot study. *J Sports Med Phys Fitness.* 2015;55(7–8):761–767.
30. Sommervold M, Østerås H. What is the effect of a shoulder-strengthening program to prevent shoulder pain among junior female team handball

players? *Open Access J Sports Med.* 2017;8:61–70. doi:10.2147/OAJSM.S127854
31. Petersen W, Braun C, Bock W, et al. A controlled prospective case control study of a prevention training program in female team handball players: the German experience. *Arch Orthop Trauma Surg.* 2005;125(9):614–621. doi:10.1007/s00402-005-0793-7
32. Wedderkopp N, Kaltoft M, Holm R, Froberg K. Comparison of two intervention programmes in young female players in European handball—with and without ankle disc. *Scand J Med Sci Sports.* 2003;13(6):371–375. doi:10.1046/j.1600-0838.2003.00336.x
33. Wedderkopp N, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball: a prospective intervention study. *Scand J Med Sci Sports.* 1999;9(1):41–47. doi:10.1111/j.1600-0838.1999.tb00205.x
34. Myklebust G, Engebretsen L, Brækken IH, Skjølberg A, Olsen O-E, Bahr R. Prevention of anterior cruciate ligament injuries in female team handball players: a prospective intervention study over three seasons. *Clin J Sport Med.* 2003;13(2):71–78. doi:10.1097/00042752-200303000-00002
35. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology, part I: pathoanatomy and biomechanics. *Arthroscopy.* 2003;19(4):404–420. doi:10.1053/jars.2003.50128
36. Pogetti LS, Nakagawa TH, Conteçote GP, Camargo PR. Core stability, shoulder peak torque and function in throwing athletes with and without shoulder pain. *Phys Ther Sport* 2018;34:36–42. doi:10.1016/j.ptsp.2018.08.008
37. Nakase K, Shitara H, Tajika T, et al. The relationship between dynamic balance ability and shoulder pain in high school baseball pitchers. *Sports Health.* 2022;14(3):397–403. doi:10.1177/19417381211019682
38. Cope T, Wechter S, Stucky M, Thomas C, Wilhelm M. The impact of lumbopelvic control on overhead performance and shoulder injury in overhead athletes: a systematic review. *Int J Sports Phys Ther.* 2019;14(4):500–513.
39. Baierle T, Kromer T, Petermann C, Magosch P, Luomajoki H. Balance ability and postural stability among patients with painful shoulder disorders and healthy controls. *BMC Musculoskelet Disord.* 2013;14:282. doi:10.1186/1471-2474-14-282
40. Garrison JC, Arnold A, Macko MJ, Conway JE. Baseball players diagnosed with ulnar collateral ligament tears demonstrate decreased balance compared to healthy controls. *J Orthop Sports Phys Ther.* 2013;43(10):752–758. doi:10.2519/jospt.2013.4680
41. Myklebust G, Maehlum S, Engebretsen L, Strand T, Solheim E. Registration of cruciate ligament injuries in Norwegian top level team handball: a prospective study covering two seasons. *Scand J Med Sci Sports.* 1997;7(5):289–292. doi:10.1111/j.1600-0838.1997.tb00155.x
42. Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train.* 2004;39(4):352–364.
43. Koshino Y, Ishida T, Yamanaka M, Samukawa M, Kobayashi T, Tohyama H. Toe-in landing increases the ankle inversion angle and moment during single-leg landing: implications in the prevention of lateral ankle sprains. *J Sport Rehabil.* 2017;26(6):530–535. doi:10.1123/jsr.2016-0004
44. Brunner R, Friesenbichler B, Casartelli NC, Bizzini M, Maffiuletti NA, Niedermann K. Effectiveness of multicomponent lower extremity injury prevention programmes in team-sport athletes: an umbrella review. *Br J Sports Med.* 2019;53(5):282–288. doi:10.1136/bjsports-2017-098944
45. Root H, Trojian T, Martinez J, Kraemer W, DiStefano LJ. Landing technique and performance in youth athletes after a single injury-prevention program session. *J Athl Train.* 2015;50(11):1149–1157. doi:10.4085/1062-6050-50.11.01
46. Sugimoto D, Myer GD, Foss KD, Hewett TE. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis. *Br J Sports Med.* 2015;49(5):282–289. doi:10.1136/bjsports-2014-093461
47. Al Attar WSA, Khaledi EH, Bakhsh JM, Faude O, Ghulam H, Sanders RH. Injury prevention programs that include balance training exercises reduce ankle injury rates among soccer players: a systematic review. *J Physiother.* 2022;68(3):165–173. doi:10.1016/j.jphys.2022.05.019
48. Grassi A, Alexiou K, Amendola A, et al. Postural stability deficit could predict ankle sprains: a systematic review. *Knee Surg Sports Traumatol Arthrosc.* 2018;26(10):3140–3155. doi:10.1007/s00167-017-4818-x
49. Rivera MJ, Winkelmann ZK, Powden CJ, Games KE. Proprioceptive training for the prevention of ankle sprains: an evidence-based review. *J Athl Train.* 2017;52(11):1065–1067. doi:10.4085/1062-6050-52.11.16
50. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer: a prospective controlled study of proprioceptive training. *Knee Surg Sports Traumatol Arthrosc.* 1996;4(1):19–21. doi:10.1007/BF01565992
51. Michell TB, Ross SE, Blackburn JT, Hirth CJ, Guskiewicz KM. Functional balance training, with or without exercise sandals, for subjects with stable or unstable ankles. *J Athl Train.* 2006;41(4):393–398.
52. Myer GD, Ford KR, Brent JL, Hewett TE. The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. *J Strength Cond Res.* 2006;20(2):345–353. doi:10.1519/R-17955.1
53. Vescovi JD, Canavan PK, Hasson S. Effects of a plyometric program on vertical landing force and jumping performance in college women. *Phys Ther Sport.* 2008;9(4):185–192. doi:10.1016/j.ptsp.2008.08.001
54. Myer GD, Ford KR, McLean SG, Hewett TE. The effects of plyometric versus dynamic stabilization and balance training on lower extremity biomechanics. *Am J Sports Med.* 2006;34(3):445–455. doi:10.1177/0363546505281241
55. Hewett TE, Stroupe AL, Nance TA, Noyes FR. Plyometric training in female athletes: decreased impact forces and increased hamstring torques. *Am J Sports Med.* 1996;24(6):765–773. doi:10.1177/036354659602400611
56. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492–501. doi:10.1177/0363546504269591
57. Myer GD, Ford KR, Barber Foss KD, Liu C, Nick TG, Hewett TE. The relationship of hamstrings and quadriceps strength to anterior cruciate ligament injury in female athletes. *Clin J Sport Med.* 2009;19(1):3–8. doi:10.1097/JSM.0b013e318190bddb
58. Chaabene H, Negra Y, Moran J, et al. Plyometric training improves not only measures of linear speed, power, and change-of-direction speed but also repeated sprint ability in young female handball players. *J Strength Cond Res.* 2021;35(8):2230–2235. doi:10.1519/JSC.0000000000003128
59. McPartlan D, Burnie L, Pollock S, Waldron M, Tallent J. The effect of combined isometric and plyometric training on musculotendinous ankle stiffness and its subsequent effect on performance in international age-group track sprint cycling. *J Sport Exerc Sci.* 2021;5(3):193–201. doi:10.36905/jses.2021.03.05
60. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train.* 2007;42(2):311–319.
61. Chimera NJ, Swanik KA, Swanik CB, Straub SJ. Effects of plyometric training on muscle-activation strategies and performance in female athletes. *J Athl Train.* 2004;39(1):24–31.
62. Al Attar WSA, Bakhsh JM, Khaledi EH, Ghulam H, Sanders RH. Injury prevention programs that include plyometric exercises reduce the incidence of anterior cruciate ligament injury: a systematic review of cluster randomised trials. *J Physiother.* 2022;68(4):255–261. doi:10.1016/j.jphys.2022.09.001.
63. Witzke KA, Snow CM. Effects of plyometric jump training on bone mass in adolescent girls. *Med Sci Sports Exerc.* 2000;32(6):1051–1057. doi:10.1097/00005768-200006000-00003

64. Kubo K, Morimoto M, Komuro T, et al. Effects of plyometric and weight training on muscle-tendon complex and jump performance. *Med Sci Sports Exerc.* 2007;39(10):1801–1810. doi:10.1249/mss.0b013e31813e630a
65. Lauersen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med.* 2014;48(11):871–877. doi:10.1136/bjsports-2013-092538
66. Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. *Sports Health.* 2013;5(6):514–522. doi:10.1177/1941738113481200
67. Gehring D, Wissler S, Mornieux G, Gollhofer A. How to sprain your ankle—a biomechanical case report of an inversion trauma. *J Biomech.* 2013;46(1):175–178. doi:10.1016/j.jbiomech.2012.09.016
68. Fagenbaum R, Darling WG. Jump landing strategies in male and female college athletes and the implications of such strategies for anterior cruciate ligament injury. *Am J Sports Med.* 2003;31(2):233–240. doi:10.1177/03635465030310021301
69. Sugimoto D, Myer GD. Prevention of anterior cruciate ligament (ACL) injury. In: Kanosue K, Ogawa T, Fukano M, Fukubayashi T, eds. *Sports Injuries and Prevention*. Springer; 2015:163–186.
70. Damiano DL, Arnold AS, Steele KM, Delp SL. Can strength training predictably improve gait kinematics? A pilot study on the effects of hip and knee extensor strengthening on lower-extremity alignment in cerebral palsy. *Phys Ther.* 2010;90(2):269–279. doi:10.2522/ptj.20090062
71. Kontopantelis E, Springate DA, Reeves D. A re-analysis of the Cochrane Library data: the dangers of unobserved heterogeneity in meta-analyses. *PloS One.* 2013;8(7):e69930. doi:10.1371/journal.pone.0069930
72. Moher D, Pham B, Lawson ML, Klassen TP. The inclusion of reports of randomised trials published in languages other than English in systematic reviews. *Health Technol Assess.* 2003;7(41):1–90. doi:10.3310/hta7410
73. Junge A, Dvorak J. Influence of definition and data collection on the incidence of injuries in football. *Am J Sports Med.* 2000;28(5 Suppl):S40–S46. doi:10.1177/28.suppl_5.s-40
74. Crossman J, Jamieson J, Hume KM. Perceptions of athletic injuries by athletes, coaches, and medical professionals. *Percept Mot Skills.* 1990;71(3 Pt 1):848–850. doi:10.2466/pms.1990.71.3.848
75. Emery CA, Roy TO, Whittaker JL, Nettel-Aguirre A, van Mechelen W. Neuromuscular training injury prevention strategies in youth sport: a systematic review and meta-analysis. *Br J Sports Med.* 2015;49(13):865–870. doi:10.1136/bjsports-2015-094639
76. Taylor JB, Ford KR, Nguyen AD, Terry LN, Hegedus EJ. Prevention of lower extremity injuries in basketball: a systematic review and meta-analysis. *Sports Health.* 2015;7(5):392–398. doi:10.1177/1941738115593441
77. Higgins JPT, Thomas J, Chandler J, et al, eds. *Cochrane Handbook for Systematic Reviews of Interventions*. Version 6.2. Updated February 2021. Cochrane; 2021. https://training.cochrane.org/handbook/archive/v6.2

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